14. (New) The simulation method as claimed in claim 10, wherein a final data record describing the actual processing can be determined by computation from the control data record with the aid of a model describing an actual response of the processing machine, and wherein at least one two-dimensional projection of the actual processing may be determined from the final data record and caused to be displayed.

15. (New) The simulation method as claimed in claim 10, wherein the response of the processing machine is described by machine parameters .

16. (New) The simulation method as claimed in claim 15, wherein the machine parameters can be at least partially changed interactively.

17. (New) The simulation method as claimed in claim 15, wherein the machine parameters comprise at least one dimension of a processing tool of the processing machine.

18. (New) The simulation method as claimed in claim 10, wherein data records are selectively used in determining the at least one two-dimensional projection.--

REMARKS

The above-identified application was filed pursuant to 37 C.F.R. 1.52(d).

We enclose herewith a copy of German patent application nos. 100 47 928.6 and 199 55 587.7 which are the priority documents for the above referenced patent application.

An English language translation of the originally filed German language application has been provided to applicants' attorney and upon information and belief constitutes a literal translation of the originally filed application. A copy of the aforesaid English language translation is attached hereto. A substitute English language specification is also provided herewith and is requested to be used as the specification for examination purposes in the United States Patent and Trademark Office. No new matter has been added to the substitute specification. A "red-lined" version of the substitute specification is also provided in order to

identify the minor grammatical changes that have been made to the substitute specification.

Original claims 1-9 have been cancelled and replaced by new claims 10-18 which are believed to conform with United States practice.

Dated: February 14, 2001

Respectfully submitted,

By: ______________________

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File A33752 (071308.0102)

PATENT

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TO ALL WHOM IT MAY CONCERN:

Be it known that WE, Dr. Wolfgang Papiernik and Dr. Christof Sinn, citizens of Germany, whose post office addresses are Im See 21, 91077 Neunkirchen, Germany; and Görzer Straße 9, 90475 Nürnberg, Germany; respectively, have invented an improvement in

SIMULATION METHOD

of which the following is a

SPECIFICATION

BACKGROUND OF THE INVENTION

The present invention relates to a simulation method for a data record which describes three-dimensional processing by a CNC-controlled processing machine, ~~in~~**for** ~~particular~~**example** a milling machine.

In the case of CNC-controlled processing machines, a workpiece is either directly coded by a programmer, or the workpiece is modeled with the aid of a CAD system and then converted into an equivalent CNC part program. The CNC part program or the CNC model correspond in this case to idealized processing instructions

for the processing machine. The CNC program is loaded into a CNC controller, and the processing machine is controlled in accordance with the CNC program.

There are no problems with this mode of procedure when ~~the~~a workpiece thus fabricated ~~lies~~falls within the desired process tolerances of an ideal workpiece. However, ~~if~~when ~~the~~a fabricated workpiece does not correspond to the requirements placed on it, the question arises as to ~~the~~what variations ~~on the basis of which~~constitute an acceptable workpiece~~ can be fabricated~~.

It is certainly possible to change sequentially ~~to change~~ individual processing instructions and/or individual operating parameters of the processing machine, to fabricate a new workpiece and then to inspect this newly fabricated workpiece. However, this mode of procedure is ~~very laborious~~labor and~~, moreover,~~material intensive ~~in terms of cost, material~~ and ~~time. This also holds~~hence costly, ~~very particularly,~~specifically because it is ~~frequently not known where~~often difficult to ~~look for~~determine the cause of the deviations of the actually fabricated workpiece from the desired workpiece.

SUMMARY OF THE INVENTION

It is the object of the present invention to create a ~~possibility of formulating, in a substantially faster, simpler and more~~fast, simple and cost-effective ~~way than in the prior art,~~procedure for formulating idealized processing instructions ~~by means of~~ which ~~it is possible in reality~~ to produce a real workpiece which ~~is~~

~~acceptable, that is to say which~~ corresponds to an ideal workpiece within ~~the~~ permissible ~~tolerance band~~**tolerances**.

The object is achieved by means of a simulation method for a data record which describes three-dimensional processing by a CNC-controlled processing machine, ~~in~~**for** ~~particular~~**example** a milling machine~~,~~**. The simulation method includes:**

- ~~a desired processing by~~ **determination of** an initial data record which describes idealized processing instructions for the processing machine ~~being determined,~~**;**

- ~~it being possible to determine~~ **determination of a control data record** from the initial data record with the aid of an ~~arithmetic~~**arithematic** unit ~~a control data record~~ for a control unit controlling the processing machine~~,~~**;** and

- ~~it being possible to determine~~ **determination of** at least one two-dimensional projection of the processing from the initial data record and/or from the control data record, and ~~to represent it via a display device.~~**representing it via a display device.**

~~The point is that it~~**According to the present invention it** is possible ~~thereby~~ to fabricate a "virtual workpiece" or ~~to~~ carry out ~~the~~**virtual** processing ~~virtually. It is therefore not necessary actually to fabricate~~**without fabricating** a workpiece. In principle, the processing machine as such need not ~~even be present.~~**even be present.**

~~When it is possible with the aid of the arithmetic unit to determine at least one intermediate data record from the initial data record and to determine the control data record from the intermediate data record, it is preferably also possible to determine from the intermediate data record a two-dimensional projection of the processing and to represent it via the display device. The point is that the simulation method can then be used even more flexibly.~~

~~The same also holds for the case in which a final~~**With the aid of an arithmetic unit to determine at least one intermediate** data record ~~describing the actual processing can be determined by computation~~ from **the initial data record and to determine** the control data record ~~with~~**from** the ~~aid of a model describing a real response of the processing machine~~**intermediate data record**, ~~and in which~~ it is **preferably** also ~~possible~~ to determine from the ~~final~~**intermediate** data record ~~at least one~~**a** two-dimensional projection of the ~~actual~~ processing and to represent it via ~~the~~**a** display device. **This enables the simulation method to be used even more flexibly.**

The same also holds true for the case in which a final data record describing the actual processing can be determined by computation from the control data record with the aid of a model describing a real response of the processing machine, and in which it is also possible to determine from the final data record at least one two-dimensional projection of the actual processing and to represent it via the display device.

~~The initial data record~~**The initial data record** is generally a part program. **Optionally,** ~~It~~**it** is ~~optionally~~ possible either for the part program itself to be assigned traversing speeds, traversing accelerations and track curvatures, or for the part program to be transformed into a polynomial series, the traversing speeds, traversing accelerations and track curvatures then being assigned to the polynomial series. Movements to be coordinated with one another~~–~~**, in two stages** if appropriate~~, in two stages –~~ ~~of~~ **such as** individual traversing options of the processing tool are then determined with the aid of the part program or the polynomial series ~~and the~~**which are then** assigned traversing speeds, traversing accelerations and track curvatures. The movements to be coordinated with one another form the control data record. In these cases, the intermediate data record preferably corresponds to the part program with the traversing speeds, traversing accelerations and track curvatures assigned to it, or to the polynomial series**,** with or without the traversing speeds, traversing accelerations and track curvatures ~~assigned to the polynomial series~~.

The real response of the processing machine can be described efficiently when this is done by machine parameters. For reasons of flexibility, the machine parameters can preferably be changed interactively at least partially in this case. As a rule, ~~they~~**the parameters** comprise at least one dimension of a processing tool of the processing machine.

The simulation method operates with particular flexibility when it is possible to select ~~–~~**,** preferably interactively ~~– which of~~**,** the data ~~records is used to~~

~~determine the~~**record which determines** at least one two-dimensional projection and **displays** the ~~representation thereof~~**same** via the display device. In order to determine the at least one two-dimensional projection, a multiplicity of interpolation points which in their entirety describe the virtual three-dimensional workpiece are preferably determined with the aid of the selected data record.

Further advantages and details ~~emerge~~**are apparent** from the following description of an exemplary embodiment~~. In this case~~ **as shown**, in the schematic representation

DESCRIPTION OF DRAWINGS

~~figure 1~~ ~~shows~~**Figure 1 illustrates** a processing machine with a computer and a control unit~~,~~**.**

~~figure 2~~ ~~shows~~**Figure 2 illustrates** the computer of ~~figure~~**Figure** 1 in detail~~, and~~**.**

~~figure 3~~ ~~shows~~**Figure 3 illustrates** a control device and a simulation and/or emulation computer.

DETAILED DESCRIPTION OF THE INVENTION

In accordance with ~~figure~~**Figure** 1, an initial data record 2 is input into a computer 1, for example a PC 1. The initial data record 2 describes idealized processing instructions for a CNC-controlled processing machine 3. It is usually a so-called part program 2. The processing machine 3 is designed as a milling machine ~~3~~

in the present instance. However, it could also be another machine tool, for example a drilling or turning machine. The processing machine 3 could also be designed as an industrial robot or ~~as~~ a ~~special~~**specialized** machine.

The initial data record 2 describes a desired processing of a workpiece 11 by the processing machine 3. In accordance with ~~figure~~**Figure** 2, the computer 1 uses its program to determine from said initial data record a control data record 4 for the processing machine 3. The control data record 4 therefore likewise constitutes a desired processing for the workpiece 11, and the computer 1 forms a CNC controller for the processing machine 3.

In order to determine the control data record 4, the computer 1 initially transforms the part program 2 into a polynomial series 6, preferably in a function block 5, the so-called compressor 5. The polynomial series 6 yields a track to be covered by a processing tool 7, here a milling head 7. The user then assigns desired traversing speeds to the polynomial series 6. The computer 1 then calculates expected traversing speeds **(**v**)**, expected traversing accelerations **(**a**),** and traversing steps **(**r**)** of the processing tool 7 as well as expected track curvatures. If these values **(**v, a, r**)** exceed permissible limiting values, the computer 1 corrects the movement guidance of the processing tool 7 correspondingly, such that permissible limiting values are observed.

The transformation of the part program 2 into the polynomial series 6 can also be omitted. In this case, the desired traversing speeds~~,~~ **and** the expected traversing

speeds (v), the expected traversing accelerations (a) and the traversing steps (r) as well as the expected track curvatures are assigned to the part program 2. It is also possible to generate the polynomial series 6 directly by means of a CAD system.

The next step is to make use, in a further function block 8 of the computer 1, the so-called interpolator 8, of the polynomial series 6 and the traversing speeds (v), traversing accelerations (a), traversing steps (r), and track curvatures assigned to it to determine movements, to be coordinated with one another, of individual - as a rule axial - traversing options of the processing tool 7. This coordination is performed in two stages, since as a rule a so-called fine interpolator 9 is arranged downstream of the interpolator 8 as a further function block 9. The output signal of the fine interpolator 9 then forms the control data record 4. The track is therefore split up into individual axes or general degrees of freedom of movement of the processing tool 7. The intermediate data records thus formed also constitute a desired processing of the workpiece 11 by the processing machine 3.

The control data record 4 determined by the computer 1 is transmitted to a control unit 10. The latter controls the processing machine 3 in accordance with the control data record 4. The processing machine 3 therefore fabricates the workpiece 11 in a fashion controlled by the control unit 10 and in accordance with the control instructions implemented in the control data record 4. In this process, inter alia, traversing paths s adopted by the processing tool 7 are detected and transmitted to the control unit 10. The control unit 10 can therefore detect a nonideal response of the

processing machine 3, in particular an elasticity response E of the processing machine 3, and compensate for it by correction.

In practice, deviations occur between the actually fabricated workpiece 11 and an ideal workpiece described by the initial data record 2. The extent of the deviations is a function of a multiplicity of factors, in particular of the transformation of the initial data record 2 into the control data record 4, the quality of the control by the control unit 10, the actual response of the processing machine 3 and the properties of the drive of the processing machine 3.

The deviations of the actually fabricated workpiece 11 from the ideal workpiece can be tolerated or not depending on their magnitude. Changes are required if the deviations cannot be tolerated. The changes in the control data record 4 can be performed in this case by changes in the initial data record 2, by changes in the transformation of the initial data record 2 into the control data record 4, by changes in the control exerted by the control unit 10, by a variation in the actual response, in particular in the elasticity response (E) and in the processing machine 3, and by adapting the properties of the drive of the processing machine 3. To the extent that properties of the processing machine 3 and/or of its drive are established, it is, of course, necessary to verify on the basis of theoretical calculations and/or experimental trials that these properties do in fact obtain.

In accordance with ~~figure~~**Figure** 3, a simulation and/or emulation computer 1~~’~~' is provided in order to achieve optimization of the actually fabricated

workpiece 11 as quickly as possible. The simulation and/or emulation computer 1~~2~~' executes a computer program product 12. The initial data record 2, the polynomial series 6, the traversing speeds (v), traversing accelerations (a), and traversing steps (r), which are assigned to the polynomial series 6, as well as track curvatures and the control data record 4, in particular, are transmitted to the simulation and/or emulation computer 1~~2~~' during execution of the computer program product 12. For this purpose, the computer program product 12 implements interfaces 13 ~~via~~**by way of** which the simulation and/or emulation computer 1~~2~~' communicates with the computer 1.

Furthermore, when executing the computer program product 12, the simulation and/or emulation computer 1~~2~~' simulates or models the control response of the control unit 10 and the actual response (including the elasticity response E) and the properties of the drive of the processing machine 3. It therefore determines by calculation with the aid of a model (M) a final data record 15 which describes a real processing of the three-dimensional workpiece 11.

The model (M) can be adapted - preferably interactively - to prescribable model parameters via a further interface 14. In particular, the elasticity response (E) of the processing machine 3 can be changed. The initial data record 2 can also be changed interactively via the further interface 14. Furthermore, it is also possible for at least one dimension (d) of the processing tool 7, for example the diameter of the milling head 7, to be changed interactively via the further interface 14. The further interface 14 is usually implemented in the form of a keyboard and/or a mouse control.

The - static and dynamic - elasticity response (E) of the processing machine 3 can be taken into account, for example, in the form of a parameterized differential equation. The description of the real properties of the processing machine 3 is therefore performed by machine parameters. The machine parameters can preferably also be changed interactively via the further interface 14. However, the elasticity response (E) of the processing machine 3 can also be taken into account by means of a finite element model (FEM) or a rigid or flexible multibody model (MKM, FMKM) or multibody system (MKS, FMKS) instead of by a parameterized differential equation.

One of the data records 2, 4, 6, 15 is selected for visualization. In the case of selection of the polynomial series 6, it is possible in the process further to distinguish whether said series is selected with or without the traversing speeds v, traversing accelerations a and traversing steps r which are assigned to the polynomial series 6, as well as the track curvatures. The selected data record 2, 4, 6 or 15 can be changed interactively in this case. It is, in particular, possible to extract only a portion of the selected data record 2, 4, 6 or 15.

The selection is also performed preferably interactively via the further interface 14. The selected data record 2, 4, 6 or 15 is then used to determine at least one two-dimensional projection. For this purpose, the selected data record 2, 4, 6 or 15 is used to determine a multiplicity of interpolation points which in their entirety describe the virtual three-dimensional workpiece.

The entirety of the interpolation points forms a display data record 16. The format of the data of the display data record 16 is a function of the selected data record 2, 4, 6 or 15. The simulation and/or emulation computer 1~~2~~' uses the interpolation points to determine the at least one two-dimensional projection of the virtual workpiece 11. This projection is represented by the simulation and/or emulation computer 1~~2~~' via a display device 17, typically a monitor 17 or a TFT display 17.

The representation of the selected data record 2, 4, 6 or 15 comprises polyhedra. If the selected data record 2, 4, 6 or 15 comprises only positional data, it is, of course, also only positional data which can be used for visualization. If, by contrast, the selected data record 2, 4, 6 or 15 also comprises data on speed, acceleration, stepping and curvature, these can also be used for visualization. For example, different speeds (v), accelerations (a), steps (r), or curvatures can be represented by different color values. If appropriate, it is also possible to undertake color transitions or color gradations between neighboring interpolation points.

The two-dimensional projections of the selected data record 2, 4, 6 or 15 can be changed interactively, as is generally customary and known. In particular, the display can be rotated such that there is a change in the viewing angle from which it is seen. Furthermore, it can be zoomed **in on** such that the imaging scale changes as a result. Furthermore, it is possible to prescribe a lighting configuration interactively.

In order to be able to assess the influence of individual function blocks 5, 8, 9 in isolation, it is further possible for the function blocks 5, 8, 9 to be masked out

interactively and individually. The masking out of one of the function blocks 5, 8 or 9 means that the masked-out function block 5, 8 or 9 is jumped over in determining the control data record 4.

If, for example, the compressor 5 is masked out, the polynomial series 6 is not determined. In this case, the traversing speeds (v) etc. are assigned to the part program 2 and - in one or two stages - the movements, to be coordinated with one another, of individual traversing options of the processing tool 7 are determined with the aid of the part program 2 and the additional data (v, a, r) assigned thereto. The control data record 4 corresponds in this case, as previously, to the movements to be coordinated with one another. In this case, of course, together with the additional data (v, a, r) assigned to it, the part program can be selected as a data record to be displayed.

Quick optimized control data records 4 for processing machines 3 of all types can be formulated easily and cost-effectively by means of the simulation method according to the invention.

~~Patent~~We ~~claims~~claim:

1. A simulation method for a data record (2, 4, 6, 15) which describes three-dimensional processing by a CNC-controlled processing machine (3), in particular a milling machine (3),

- a desired processing by an initial data record (2) which describes idealized processing instructions for the processing machine (3) being determined,
- it being possible to determine from the initial data record (2) with the aid of an arithmetic unit (1) a control data record (4) for a control unit (10) controlling the processing machine (3), and
- it being possible to determine at least one two-dimensional projection of the processing from the initial data record (2) and/or from the control data record (4), and to represent it via a display device (17).

2. The simulation method as claimed in claim 1, wherein it is possible with the aid of the arithmetic unit (1) to determine at least one intermediate data record (6) from the initial data record (2) and then to determine the control data record (4) from the intermediate data record (6), and wherein it is also possible to determine from the intermediate data record (6) at least one two-dimensional projection of the processing and to represent it via the display device (17).

3. The simulation method as claimed in claim 2,

- wherein the initial data set (2) is a part program (2),
- wherein the part program (2) can be assigned traversing speeds (v), traversing accelerations (a) and track curvatures,

- wherein the part program (2) and the traversing speeds (v), traversing accelerations (a) and track curvatures which can be assigned thereto are used to determine movements to be coordinated with one another – if appropriate, in two stages - of individual traversing options of the processing tool (7), the movements to be coordinated with one another forming the control data record (4), and
- wherein the intermediate data record corresponds to the part program (2) with the traversing speeds (v), traversing accelerations (a) and track curvatures assigned to it.

4. The simulation method as claimed in claim 2,

- wherein the initial data set (2) is a part program (2),
- wherein the part program (2) can be transformed into a polynomial series (6),
- wherein the polynomial series (6) can be assigned traversing speeds (v), traversing accelerations (a) and track curvatures,
- wherein the polynomial series (6) and the traversing speeds (v), traversing accelerations (a) and track curvatures which can be assigned thereto are used to determine movements to be coordinated with one another of individual traversing options of the processing tool (7), the movements to be coordinated with one another forming the control data record (4), and

- wherein the intermediate data record (6) corresponds to the polynomial series (6) with or without the traversing speeds (v), traversing accelerations (a) and track curvatures assigned to the polynomial series (6).

5. The simulation method as claimed in one of the above claims, wherein a final data record (15) describing the actual processing can be determined by computation from the control data record (4) with the aid of a model (M) describing a real response of the processing machine (3), and wherein it is also possible to determine from the final data record (15) at least one two-dimensional projection of the actual processing and to represent it via the display device (17).

6. The simulation method as claimed in claim 5, wherein the response of the processing machine (3) is described by machine parameters (E, d).

7. The simulation method as claimed in claim 6, wherein the machine parameters (E, d) can be changed interactively at least partially.

8. The simulation method as claimed in claim 5, 6 or 7, wherein the machine parameters (E, d) comprise at least one dimension (d) of a processing tool (7) of the processing machine (3).

9. The simulation method as claimed in one of the above claims, wherein it is possible to select - preferably interactively - which of the data records (2, 4, 6, 15) is used to determine the at least one two-dimensional projection and the representation thereof via the display device (17).

10. The simulation method as claimed in claim 9, wherein a multiplicity of interpolation points which in their entirety describe the processing are determined with the aid of the selected data record (2, 4, 6, 15).

11. The simulation method as claimed in claim 9 or 10, wherein the selected data record (2, 4, 6, 15) can be changed interactively.

12. A computer program product for carrying out a simulation method as claimed in one of the above claims.

13. A simulation and/or emulation computer programmed with the aid of a computer program product as claimed in claim 12.

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PATENT

Abstract

~~Simulation method~~

~~Three~~**A simulation method for three**-dimensional ~~(desired)~~ processing by a CNC-controlled processing machine ~~(3)~~ is determined by means of an initial data record ~~(2)~~ which describes idealized processing instructions for a processing machine ~~(3). It is possible to determine from the initial data record (2) with the aid of an arithmetic unit (1)~~**, wherein** a control data record ~~(4)~~ for a control unit ~~(10)~~ controlling the processing machine ~~(3). It~~ is ~~possible to determine at~~**determined from the initial data record by means of an arithmetic unit. At** least one two-dimensional projection of the processing **is determined** from the initial data record ~~(2)~~ and/or ~~from~~ the control data record ~~(4),~~ and ~~to represent it via a display device (17)~~**is displayed**.

~~FIGURE 3~~